Special Issue Honouring Helias A. Udo de Haes: LCA Methodology

Notions on the Design and Use of an Ideal Regional or Global LCA Database

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Abstract

Goal, Scope and Background. More and more national and regional life cycle assessment (LCA) databases are being established satisfying the increasing demand on LCA in policy making (e.g. Integrated Product Policy, IPP) and in industry. In order to create harmonised datasets in such unified databases, a common understanding and common rules are required. This paper describes major requirements on the way towards an ideal national background LCA database in terms of co-operation, but also in terms of life cycle inventory analysis (LCI) and impact assessment (LCIA) methodology.

Methods. A classification of disputed methodological issues is made according to their consensus potential. In LCI, three main areas of dissent are identified where consensus seems hardly possible, namely system modelling (consequential versus attributional), allocation (including recycling) and reporting (transparency and progressiveness). In LCIA the time aspect is added to the well-known value judgements of the weighting step.

Results and Discussions. It is concluded that LCA methodology should rather allow for plurality than to urge harmonisation in any case. A series of questions is proposed to identify the most appropriate content of the LCA background database or the most appropriate LCI dataset. The questions help to identify the best suited approach in modelling the product system in general and multioutput and recycling processes in particular. They additionally help to clarify the position with regard to time preferences in LCIA. Intentionally, the answers to these questions are not attributed to particular goal and scope definitions, although some recommendations and clarifying explanations are provided.

Recommendations and Perspective. It is concluded that there is not one single ideal background database content. Value judgements are also present in LCI modelling and require pluralistic solutions; solutions possibly based on the same primary data. It is recommended to focus the methodological discussion on aspects where consensus is within reach, sensible and of added value for all parties.

Keywords: Allocation; consensus finding; LCA database; life cycle assessment (LCA); life cycle inventory data; recycling; time preference; value choices

Introduction

The production chains of consumer goods are more and more subdivided and tend to spread over the entire globe. Many products may be purchased at any place on the world. Swiss watches may contain a Lithium ion battery produced in France with Lithium from Chile. They are packed in brushed aluminium boxes made in China with bauxite from Australia and sold via a Hong Kong dealer. This comes along with an increase in environmental pressure due to a growing world economy as well as an increase in knowledge on the limits of nature's capacity to absorb pollution.

In the European Union, the green paper on 'Integrated Product Policy (IPP)' (European Commission 2001) emphasises the importance of life cycle considerations on products and services in order to improve their environmental performance and to avoid suboptimisation. Some new European directives include life cycle thinking such as the proposal of a European directive on Eco-Design requirements of Energy-Using Products (European Commission 2003).

One consequence of these developments is the increased attention dedicated to life cycle assessment (LCA) by industry, legislative bodies and academia all over the world. UNEP got aware of the promising power of life cycle assessment and launched the life cycle initiative together with SETAC. Main objectives of the UNEP-SETAC life cycle initiative are to

- identify best practice indicators and communication strategies for life cycle management;
- provide a basis for capacity building;
- expand the availability of sound LCA data and methods;
- facilitate the use of life cycle based information and methods.

In the early days of the Life Cycle Initiative, Helias Udo de Haes pushed in particular the idea of a peer reviewed, and regularly updated LCI database or information system that represents best LCI practice, similar to what he strives for in terms of life cycle impact assessment (Udo de Haes et al. 2002b).

For an efficient decision support on the basis of life cycle assessment information, availability of sound LCI data and easy use of life cycle based information are crucial. Product and service life cycle assessments are very much dependent on reliable and comprehensive background databases that complement individually modelled manufacturing, operation, dismantling and waste management processes. Fortunately, information and communication technologies developed rapidly during the past years and allow for smart and efficient database solutions. This paper elaborates and discusses the needs, the prerequisites and the design and use of an ideal regional or global database for LCA. After an analysis of the current situation in Section 1, three main requirements in view of an ideal background LCA database are stated, one on co-operation (in Section 2.1), one on consensus-finding in life cycle inventory analysis (LCI, in Section 2.4) and one on consensus-finding in life cycle impact assessment (LCIA, in Section 3). Issues where consensus seems impossible to reach are identified and described in detail in

Sections 2.2 and 2.3. Section 4 contains a proposal of a set of questions that help to identify the appropriate LCA database. The paper ends with a discussion in Section 5.

In this article both terms, 'LCI database' and 'LCA database', are used. Many aspects treated in this paper deal with LCI related problems. However, the interaction with life cycle impact assessment is considered important and it is suggested that regional or global databases do include the LCIA information as well. In cases in which the entire database is meant, the term LCA database is used in this paper in opposition to the cases where mainly inventory problems are discussed or described.

1 Analysis of Current Situation

Centralised LCI databases are being established within the last few years in different countries such as the United States of America, Japan, Germany and Switzerland. An analysis of the achieved results reveals that cultural differences, the differences in the grown structure of the LCA community (institutional and content related interests) and differences in available budget are major causes for differences in database outline, workflow and database content.

At a first glance, the situation in Japan and Switzerland seem to be quite similar. The government of both countries got aware of the promising power of life cycle assessment within the portfolio of instruments supporting environmental policy. As a consequence, the administrations within each country joined forces to promote the development of LCI and LCIA methodology and of LCI data. Doing so, LCA research institutes and consultants as well as LCA departments in industry were gently forced to work together and to harmonise their individual and partly incompatible LCI modelling approaches. One major distinction between the Japanese and the Swiss approach is the difference in industry involvement. While the Japanese LCA programme involved industry participation on the strategic and operational levels, the Swiss LCI database initiative, and especially the database outline and its modelling principles, are based mainly on inputs and the LCA experience of academic, consulting and governmental bodies.

The aims and the outcome of the two initiatives are also quite different. Three aspects of the two national initiatives serve as an illustration (**Table 1**). Japan encompassed projects in LCI and LCIA, whereas the Swiss ecoinvent 2000 project was limited to LCI data investigation and the interface to existing LCIA methods. The set of elementary flows considered in LCI data investigation is rather limited in Japan, whereas comprehensiveness was one of the aims in the Swiss project. Finally, the activities of Japan's industry defined the products and services analysed in the Japan LCI, whereas the Swiss scope was determined by the requirements of background LCA databases and, hence, contains only very few consumer goods.

It seems that unified national LCA databases rather try to focus on datasets on the 'commons', i.e. datasets on energy and basic materials supply and on transport and waste management services. The initiative of creating a German network on life cycle inventory data, for instance, aims to establish the network as the common information and coordination platform of all groups involved in the supply and use of life cycle inventory data. According to the plans, the German data pool shall comprise harmonised and reviewed data for background systems ('basic fields of life cycle analyses', Bauer et al. 2004).

But how should such a 'background database' look? What should it encompass, what not? Should methodological developments be pushed by providing more detailed LCI information than current practice in LCIA requires or should background databases follow methodological developments that are broadly accepted in LCA practice? Should LCI background databases allow for a plurality in methodological approaches (allow for modelling choices) or should they prescribe the good practice once and for all LCA practitioners? How could such plurality be implemented in background databases, if plurality is accepted, i.e., if several good life cycle inventory analysis practices are possible and reasonable? The next three sections try to provide some answers to these questions, distinguishing life cycle inventory analysis, life cycle impact assessment and a proposal on how to identify the most suited LCA database.

2 Life Cycle Inventory Requirements

2.1 Seek for co-operation

The product system of any product includes (to a variable extent) the diversity of the world's economy, i.e. mining industry, energy industry, heavy industry, building industry, chemicals industry, electronics industry, farming and food industry, transport services, programming services, finan-

Table 1: Comparison of the scope of the Japanese and the Swiss life cycle assessment initiatives; selected aspects

Aspect	Japan	Switzerland
LCA phases covered	LCI data, methodology and database as well as LCIA method developments (LIME, JEPIX)	Main focus on LCI data and database and the interface between current LCIA methods and the LCI database
elementary flows covered	LCI database limited to 14 air- and waterborne pollutants	Strive for an extension of quantified LCI parameters (e.g. land use, differenciation of size of particulate matters emitted)
product groups covered	Rather focused on major products and services (including consumer goods) delivered by Japanese industry	Rather focused and fairly complete on background data with a European scope (such as energy and material supply and transport and waste management services) but only very few consumer goods
Reference	(Narita N et al. 2003)	(Frischknecht et al. 2004)

Narita N, Nakahara Y, Morimoto M, Aoki R, Suda S (2003): The LCA Data Library – A Result of National LCA Project in Japan. In InLCA / LCM 2003, September 22–25, 2003. <www.lcacenter.org/InLCA-LCM03/Narita-presentation.pdf>, Seattle, Washington, USA
Öko-Institut (2005): Global Emission Model for Integrated Systems; GEMIS 4.2for <http://www.oeko.de/service/gemis/en/index.htm>, Darmstadt

cial and legal services, waste management services and the like. Because production and service provision is globalised, an ideally complete LCA database covers main activities in all parts of the world. Furthermore, the ideally complete LCA database not only includes all these datasets, but at the same time should include the links in between them according to economic interrelations. This would result in a huge number of interlinked datasets and an even larger number of links (inputs and outputs). Creating and maintaining such a database asks for joining resources and sharing work due to several reasons:

– the expertise of individual LCA research groups, LCA consultants and LCA industry representatives is limited compared to the broad technical and environmental knowledge required
– the more remote a process takes place (from the person analysing it), the less knowledge he or she has on potential data sources and experienced local people.
– The sheer dimension of such a task makes it very improbable that it might be funded by one single commissioner nor that it might be carried out by one LCA institute.

Hence, the *first requirement* on the way towards a common LCA database can be formulated as follows: LCA institutes and consultants, LCA funding bodies and industry should seek for national and international co-operation to gain synergies and to share work.

However, to share life cycle inventory analysis, work is easier said than practiced. Ph.D. students and professors are not paid to find consensus but to search for new solutions and approaches. Co-operation requires mutual or explicit understanding on how to model product systems and may slow down our own research activities. The following section introduces a distinction between issues where consensus can or has been reached and issues where it is difficult or hardly possible to reach consensus.

2.2 Can methodological consensus always be reached?

In Europe, several research and research co-ordination projects have been and are being carried out to harmonise LCA methodology, such as LCANET (Udo de Haes & Wrisberg 1997), CHAINET (Wrisberg et al. 2002) or COST action 530, some of which were initiated and/or lead by Helias Udo de Haes. The SETAC Europe working groups working in two 3-year frameworks in the nineties were partly used to establish or at least to work towards a best practice in LCA. Discussions within ISO during the establishment of the first series of LCA standards, however, showed that consensus-finding is not an easy task. The room for interpretation in the current LCA ISO standards – and subsequently the number of diverging interpretations of one and the same standard – is rather large. It was not possible to settle some of the hot issues (like allocation, see below) and to agree on common positions, neither in LCI nor in LCIA. However, if globally acceptable LCI background data are an aim, such contradictions and controversies must be overcome in one way or the other. In the following, life cycle inventory discussion topics are described and classified according to their consensus potential.

The co-operating institutes must agree on common rules on how to model the numerous and diverse product systems. Allocation and cut-off rules, recording rules of pollutants, data gaps treatment and many more modelling aspects need to be defined. Additionally, an agreement on the naming of pollutants and on naming rules of economic inputs and outputs is required. A large part of these agreements involves no or little subjectivity and value judgements. But even naming rules are not only a matter of convention, but also of diverging concepts and thus disputable. Astonishing enough that the SETAC working group on data quality and availability arrived at a consensus in elementary flows nomenclature (Hischier et al. 2001).

Agreements on some other issues are more tricky, not necessarily because they involve severe value judgements, but more because of differences in schools and long-term tradition. They may be called LCI modelling conventions and flow reporting conventions. Among them, the modelling of the natural carbon cycle, the classification and grouping of elementary flows, or the modelling of waste (either as input or as an output) may serve as examples. Without principally changing the final results of an LCA on biofuels, biogenic carbon can be modelled including or excluding carbon uptake during biomass growth. Some LCA practitioners prefer to consider carbon uptake in their LCA models, whereas others prefer not to do so. Some schools teach one to group elementary flows within a hierarchy (where all emissions of individual non-methane volatile organic carbons (NMVOC) such as benzene or formaldehyde are added up to a cumulative total NMVOC emission, and showed in parallel to cumulative benzene and formaldehyde emissions), whereas others prefer not to introduce such a hierarchy and to record each substance only once (on the most detailed level). Some distinguish pollutants according to receiving media and the source of emission, whereas others further subdivide the receiving compartments instead. Waste may be modelled on the output side as well, if the physical flows are used as an analogy[1]. Others prefer not to model according to the physical flow of the wastes, but rather based on the service purchased, namely the waste treatment service, which is a (service) input into the process that 'produces' the waste.

All the examples mentioned so far do not involve severe value choices. These modelling options do not (or only marginally) influence the outcome of an LCA. However, a harmonisation on these issues involves reworking of LCA models, LCA software routines and interfaces, and potentially also of tutorials and manuals at least for parts of the LCA community. It may also be perceived as a matter of prestige that one's own approach is chosen as the internationally accepted one. That is why consensus finding is certainly not an easy walkover.

Finally, there are some really tough aspects where consensus finding is an ongoing task and may be unreachable in itself. This includes aspects that are usually dominated by personal opinions, cultural perspectives or by position-ori-

[1] These waste outputs to technosphere are sometimes called 'bads', similar to the 'goods', the intended products and services delivered.

ented thinking. Economists, for instance, have been struggling since more than 150 years with the problem of cost allocation without reaching a consensus on the 'right' approach. Currently three main fields of dissent can be identified:

– LCI modelling
  • attributional (descriptive) versus consequential (change oriented) modelling in general
  • different approaches of consequential modelling
– allocation
  • in joint (and quasi joint) production
  • in recycling
– reporting
  • level of transparency required
  • level of sophistication required

These three fields are elaborated on in the following section.

2.3 Three fields of dissent in life cycle inventory analysis

LCI modelling. In the mid nineties, the distinction between decision-oriented and descriptive LCA has been introduced, discussed and further refined (Ekvall 1999, Ekvall et al. 2004, Ekvall & Weidema 2004, Frischknecht 1998, pp. 53–76, Weidema 2001). Already before, 'what-if' scenarios have been introduced by asking 'what differences would the non-production of a product make?' (see e.g. Heintz & Baisnée 1992, p. 43). According to the distinction, consequential LCA should be applied in cases where LCA supports a decision (such as product comparison, process optimisation, investment decision, etc.). Descriptive LCA should be applied in cases of reporting purposes (such as the annual environmental report of a company, in which last year's inputs and outputs are documented). This distinction is an attempt to classify LCA goals in view of differences in LCI modelling. However, not all LCA practitioners strictly follow this distinction and quite a few LCA practitioners hesitate to apply a strictly consequential modelling in decision-oriented LCAs.

Whereas the descriptive LCA model is rather undisputed (theoretically founded in Heijungs 1997), the correct modelling approach of consequential LCA is still subject to debates. Different views exist which result in rather different LCI models and finally LCA outcomes (Frischknecht 2002). The main point of discussion is whether or not actual economic relations are followed to identify the suppliers in the situation after the decision has been taken. Some proponents (Ekvall et al. 2004, Ekvall & Weidema 2004, Weidema 2001) of the consequential approach use market information and price elasticities to identify those suppliers that are affected by the decision (without necessarily having an economic (contractual) link to the process under study) and will increase or decrease their production. Others plea for the consideration of the actual (future) suppliers based on factual economic b2b relationships (Frischknecht 1998).

Allocation. Multi-output processes are subject to lively debates when it comes to allocation. The ISO standard 14041 describes a stepwise procedure that shall be applied (International Organization for Standardization (ISO) 1998), namely

– avoid allocation wherever possible (by either further detailing the analysis or expanding the product system),
– apply physical relationships,
– apply other relationships.

System expansion may be modelled with an avoided burden or a basket of benefits approach. Weidema (2001) argues that if a consequential modelling is applied, the allocation problem does not exist because consequential modelling automatically leads to the 'avoided burden' approach. Others argue that the avoided burden approach only defines the (maximum) benefit, that can be achieved with co-production and that it is still in question to whom how much of this benefit should be attributed (Frischknecht 2000, Frischknecht & Jungbluth 2003). Kagawa & Suh (2005) describe that each approach has its correspondence in make-use tables of input-output analysis, namely the commodity technology model (system expansion) and the industry technology model (partitioning). But there, the choice of one or the other model is not that crucial in terms of results because of the macroeconomic scope of input-output analyses.

Modelling of recycling processes are also subject to controversial discussions. The ISO standard again is not very precise and leaves room for interpretation and choice. Some LCA researchers and practitioners follow an 'avoided burden' approach and grant credits to the system under analysis irrespective of the time dimension. Material quality aspects may be considered via, e.g. differences in sales prices (see, e.g., Werner 2002). But similar to the joint production case above, such an approach only defines the total achievable benefit. In most cases where the avoided burden approach is followed, the benefit is fully attributed to the product system delivering material to be recycled. The one purchasing recycled materials does not profit at all, which may be considered unfair. This automatism, however, can be avoided by first applying the avoided burden approach to determine the maximum benefit and, secondly, to apply conventional allocation to distribute the benefit among those who made this benefit possible (i.e., the ones supplying recyclable material and the ones using recycled materials).

Reporting: The ISO standards make quite clear statements when it comes to LCA reporting requirements. The LCA report shall cover – among other things – a qualitative and quantitative description of unit processes, the source of published literature, and calculation procedures (International Organization for Standardization (ISO) 1998, p. 14). This, in principle, sets a rather high reporting standard in terms of transparency and reproducibility. However, the usefulness and appropriateness of such an open reporting policy is questioned. Eyerer et al. (2004), for instance, claim that reporting cumulative LCI results only (instead of unit process raw data) increase data quality (because industry is more willing to share information as long as no details are revealed) and increases user comfort (because a user prefers 'ready to use'-datasets). Others, like Frischknecht (2004), plea for open and transparent information in background databases without diminishing the comfort of 'ready to use' datasets. This may be achieved by providing both cumulative results and unit process data.

How far should public background LCI databases be used to foster methodology developments in impact assessment? An active and a reactive attitude can be identified. The reactive approach would limit LCI investigations to elementary flows (and potential compartment differentiations) for which characterisation, damage or weighting factors are available in current LCIA methods. The active approach would go further and try to stimulate LCIA method development by quantifying elementary flows not yet considered in LCIA. Of course, the structure and parameters of newly introduced elementary flows should fit to future impact assessment approaches.

It will be hardly possible to reach full consensus on the issues listed and sketched above. However, one might strive for a classification of key questions and possible (or most probable) answers. It would help to separate consensus items from items where a plurality of approaches cannot be avoided. A potential solution on how to treat the aspects that most probably will remain disputed is described in Section 4.

2.4 Conclusion

In summary, the *second requirement* for an ideal background database is: Strive for a consensus on LCI modelling conventions and flow reporting conventions within your database initiative and classify subjective LCI methodology issues to a few standard choices.

Once these content related issues have been harmonised or opposing positions clarified, the issue of data format harmonisation may be tackled. This again seems to be a technical rather than a content-related issue. Main obstacles may be major conceptual differences, on one hand, and investment protection arguments due to major software and database content adjustment work caused by a data format harmonisation, on the other.

3 Life Cycle Impact Assessment Requirements

Discussions on best practice life cycle impact assessment (LCIA) are more intense as compared to discussions on life cycle inventory best practice. Since the early nineties, when the CML guide and background reports have been published (Heijungs et al. 1992a, Heijungs et al. 1992b), the LCA community strived for best practice consensus in impact assessment. The initiative and engagement of Helias Udo de Haes in the SETAC Europe working groups on life cycle assessment resulted in two reports on the state of the art and the ways towards best practice in impact assessment (Udo de Haes 1996, Udo de Haes et al. 2002a). The current best practice and the ISO standard (International Organization for Standardization (ISO) 2000) distinguish at least between those elements of the impact assessment phase that are mainly based on natural sciences (the fate, exposure and damage assessment) and those parts that are predominantly social science based (the weighting step).[2]

[2] Such a distinction is hardly made yet in life cycle inventory analysis.

Ideally, the development of new impact assessment methods and of LCI databases should go hand in hand to maximise the compatibility between those two LCA phases. Within the ecoinvent 2000 project, an attempt was made to integrate latest developments in the impact assessment of land use. An LCA discussion forum on land use issues has been organised in 2001 before data investigation started. On the one hand, land use and biodiversity experts explained the data demand that allows for an optimal assessment of land use transformation and occupation. On the other hand, inventory people described the possibilities within the given scope of the ecoinvent database project (constrained in terms of budget and time as well as defined in terms of processes to be analysed). The day was used for constructive consensus finding, where both groups had to make concessions. It resulted in quality guidelines, that formed the basis for the life cycle inventories investigated later-on (Frischknecht et al. 2004a, pp. 27–32, Jungbluth & Frischknecht 2001).

The time aspect gained attention in the recent past. Long-term landfill leakages may tend to dominate certain CML impact categories such as acquatic ecotoxicity, for instance in electronics LCAs, when applying the landfill model developed by Gabor Doka within the ecoinvent 2000 project (Doka & Hischier 2004). According to this model, emissions within the first hundred years after waste disposal, and after this period up to 60,000 years (which equals about the average time period between two ice ages), are quantified. During the intensive and partly emotional discussions within the ecoinvent team on whether or not to weight long-term and short-term emissions equally, it became apparent that no consensus was and is possible. Both groups brought forward a series of arguments which were not able to convince the others (Frischknecht et al. 2004b, pp. 5–10). This is at least an indication that time preference appears to be another aspect of LCA databases where consensus cannot be reached and where the diversity in values and cultural perspectives needs to be acknowledged. However, there was a consensus that no higher degree of temporal differentiation (as compared to the classification in short-term and long-term) is required (Hellweg & Frischknecht 2004).

Regional differentiation, a kind of sister of time differentiation, is discussed in particular with respect to acidification and nutrification. Depending on the region where acidifying substances are deposited, more or less damage occurs mainly depending on the available buffer capacity of calcareous soils. That is why regionalised characterisation models have been proposed in the past (Potting & Hauschild 1997a, Potting & Hauschild 1997b). Such highly differentiating impact assessment methods ask for information on the geographic location of the release of pollutants in the inventory (e.g. country-wise). Such a country-wise recording of pollutants emissions is technically not problematic under the premise that each dataset bears the information on its location (nation, region or organisational body such as international electricity networks). Each pollutant emitted by a process may be automatically linked to the respective location code. However, this would dramatically in-

crease the amount of datapoints in the LCI result of each dataset. This increase in datapoints would make it even more difficult than at present to identify errors, if efficient analysis strategies and tools are not developed and used in parallel. It is doubted whether a further regional differentiation will be implemented in background databases, although there seems to be good reasons for it.

A common regional or global LCA database should be able to accommodate the variety of impact assessment methods available. Ideally, it models the different impact assessment elements separately. Once the best practice characterisation models have been identified (ideally just one per impact category), they may be implemented in all ISO-compatible LCIA methods and, in that way, help to further standardise the LCA method.

In view of an ideal background LCA database, the following *third requirement*, related to impact assessment, is formulated: Strive for consensus on environmental impact characterisation, but allow a variety in approaches in normalisation, grouping and weighting, including time preference.

4 Identifying the Most Appropriate Background Database Content

The general technical solution of an ideal regional or global LCA database should take into account the three requirements highlighted above. It should communicate in a common data (exchange) format, offer centralised naming lists, be based on unit processes, and include the calculation of life cycle inventory and impact assessment results. Work of co-operating partners can best be supported with web services.

As we have seen, several aspects of life cycle inventory analysis and life cycle impact assessment are subject to value choices. Therefore, the user shall make a limited number of explicit (subjective) choices before accessing a database or choosing one particular dataset. The questions are selected and formulated under the (idealised) premise that all other properties (such as geographical, temporal or technology validity) do not differ between the datasets available. The answers to these questions are used to suggest (not to prescribe) to the user the appropriate (consistent) database content. The seven questions deal with LCI modelling in general, with allocation and with the time aspect in impact assessment. The questions and their sequence are shown in **Table 2**. Please note that these seven questions are not limitative. Additional questions, e.g. on whether to consequently apply allocation based on physical or on economic properties (see Guinée et al. 2004), or to allow for mixed approaches, can and should be added. For the sake of clarity and focus, we limited ourselves to the questions listed below.

The answers specify the most appropriate content of the LCA background database and its datasets. Depending on the answers given, the system model will have a different shape and the cumulative LCA results may be distinctly different. The technical solution of this differentiation may look as follows: Each dataset contains the relevant information and data describing the underlying modelling approach. Product systems are then established automatically based on the choices made related to the seven questions listed above (and perhaps a few more questions not mentioned here). Parameters to guide the system building procedure is part of such a basic data base. These parameters help to select and combine individual unit process (single and multi-function) datasets to form product systems according to the modelling choices made.

The following example on low voltage electricity supply illustrates the concept of variable data sets. Different product systems of the same functional unit (low voltage electricity, supplied by the UCTE network) exist. They serve differing modelling approaches, and consist of partly similar, and partly completely different unit processes. On the one hand, the combined heat and power plant multi-output processes may be the same, but differing allocation concepts are applied (allocation and avoided burden). On the other hand, the shares and technologies representing the electricity mix will differ substantially (e.g. differing share of wind power, differing technology level of hard coal power plants) due to attributional or consequential modelling.

It is emphasised that the seven questions listed above are deliberately formulated on a technical level and not on the level of the goal and scope of the study. Of course one could think of a system of questions on the goal and scope of the study that automatically proposes (or even prescribes) the 'right' modelling approach. Because of its subjective nature, it is nevertheless doubted whether such an automatism would be widely accepted.

Four combinations of answers shall exemplify the differences in modelling approaches (**Table 3**):

1. A consequential modelling using market analysis, applying the avoided burden concept on multi-output processes and recycling, has been designed by Ekvall & Weidema (2004).
2. A decision-oriented model approach based on (future) b2b relations applying allocation on multi-output processes and cut-off for recycling is described in Frischknecht (1998).
3. The ecoinvent data v1.2 is modelled according to the attributional approach, applying allocation on multi-output processes, the cut-off approach on recycling and including long-term emissions (ecoinvent Centre 2005). This also applies to many other LCI data sources, such as the APME-plastics or the IISI steel data. Some datasets, however, may be used and recombined with others to build a consequential database.
4. GEMIS database is based on attributional modelling, applying the avoided-burden concept with no explicit statement on long-term emissions (Öko-Institut 2005).

Other combinations are of course possible. Pragmatic simplifications, for instance, have been made in the past by apply-

ing a kind of consequential approach on the foreground system (or on the most relevant processes) and relying on attributional data in the background system.

It is hardly affordable to provide several alternative LCA datasets on hundreds and thousands of products and services at once. Hence, LCA database providers are advised to present their (raw) data on a unit process level. This allows the user to adapt LCI process data to his or her specific needs or to the preferences of the commissioner:

- Allocation principles or factors may be changed,
- the appropriate modelling approach may be chosen (attributional or any kind of consequential), and / or
- the time preference may be adjusted by including or excluding long-term emissions.

Table 2: Seven questions that help to specify the most appropriate content of the LCA background database

No	Topic	Question	Explanation
1	on system modelling in general	Do you prefer to use a consequential or an attributional approach?	Consequential LCA models are better suited in case LCA is used for decision support. Attributional LCA is better suited for the documentation of past activities.
	Consequential → go to Question 2 Attributional → go to Question 3		
2	on consequential system modelling	Do you prefer to model the market consequences of your decision irrespective of your factual (future) economic (b2b) relations, or do you prefer to consider your factual (future) economic (b2b) relations?	When modelling according to market consequences, the LCI model will include those processes that are ultimately affected by the decision. Those processes do not necessarily coincide with the ones of the actual suppliers or subsuppliers. Example "market consequences": Although a manufacturer decides to purchase hydroelectric power, the product system might include fossil electricity because the capacity of hydroelectric power is constrained and fossil power plants are the ones affected by the decision. Example 'b2b relations': If a manufacturer decides to purchase hydroelectric power, the product system shall include this hydroelectric power production because the factual economic (b2b) relation supports the operation of that power plant.
	go to Question 3		
3	on allocation in multi-output processes	Do you prefer to apply system expansion (avoided burden) or allocation according to physical or other relationship with regard to multi-output processes in the background database?	–
	system expansion (avoided burden) → go to Question 4 physical or other properties → go to Question 5		
4	on allocation within the avoided burden approach	Do you prefer to attribute 100% of the credits to the multi-output process or do you prefer to individually fix the credit share between multi-output process and purchaser of the co-product(s)?	–
	go to Question 5		
5	on allocation in recycling	Do you prefer to apply system expansion (avoided burden), cut-off or another approach (e.g., physical properties, economic value or number of subsequent uses) with regard to recycling?	–
	system expansion (avoided burden) → go to Question 6 other answers → go to Question 7		
6	on allocation within the avoided burden approach	Do you prefer to attribute 100% of the credits to the product system delivering material to be recycled or do you prefer to individually fix the credit share between supplier and purchaser of the material to be recycled?	–
	go to Question 7		
7	on time preferences in life cycle impact assessment	Do you prefer to weight long-term emissions and impacts (occuring after about 100 years from the time for which the LCA is carried out) and short-term emissions and impacts (occurring within the first 100 years) differently?	To be treated according to the time horizon chosen in damage assessment

Table 3: Dataset properties of individual data sets according to database modelling approaches

References	Modelling	Allocation	Time preference
(Ekvall & Weidema 2004)	Consequential, market information	Multi-output allocation and recycling: avoided burden	No explicit statement
(Frischknecht 1998)	Consequential, (future) b2b relations	Multi-output allocation: physical or economic relationships recycling: cut-off	No time preference
(ecoinvent Centre 2005)	Attributional; adjustable to consequential	Multi-output allocation: physical or economic relationships recycling: cut-off	No time preference
(Öko-Institut 2005)	Attributional	Avoided burdens	No explicit statement

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5 Discussion

Information and communication technology offers technical solutions that cover nearly all needs we have or might think of. Hence, the creation of a regional or global LCA database is perceived to be more of a challenge because of the 'human factors'. Consensus finding on LCI methodology, in particular on the general modelling approach and on allocation and recycling, and consensus finding in LCIA seem to be the most challenging steps on the way towards a common regional or even global LCA database. Aspects such as LCI modelling or allocation involve value judgements and subjectivity and it is doubted whether it is useful to try to reach consensus at all (or even enforce one particular approach). To allow for a plurality of approaches and to try to support such a plurality with transparent and open LCI databases is strongly preferred.

Other obstacles on the path towards a national or regional LCA database are built up to the inherent purpose of research and academic institutions and due to achieved positions and tradition. Ph.D. students need to create new solutions and methodological approaches and not to debate on potential consensus. Aspects like naming rules or reporting conventions for pollutants do not really involve value choices. But it may involve quite some resources in terms of time and money for some or even all actors to change from their own system to a new one. And such investments require clear incentives and expected advantages.

The availability of large unified background LCI databases will certainly foster the application of LCA. However, it does not automatically unify LCI and LCA methodology nor standardise LCA results. Controversial discussions on the diverging outcome of LCAs will for sure happen also in the future, even if based on the same source of data. This is inherently due to the fact that not only LCIA but also LCI includes value choices and subjective aspects. However, it would be wrong to disqualify LCA due to its missing uniformity. Plurality in LCA only reflects plurality in society. It is strongly believed that any developments in LCA methodology trying to embed this plurality rather than to exclude it strengthens the tool.

Helias Udo de Haes had and has a good sensorium to feel how far harmonisation efforts may go in life cycle impact assessment and where no consensus may be reached. A strong focus on aspects where harmonisation seemed possible allowed for substantial progress in the last years. Such a distinction and concentration on consensus-promising issues has not yet taken place in the field of LCI. The proposed list of questions in relation with background LCA databases may help to structure these issues and focus the methodological discussion on aspects where consensus is within reach, sensible and of added value for all parties.

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